International Journal of Computer Science and Information Technology
ISSN: 3005-9682 (Print), ISSN: 3005-7140 (Online) | Volume 3, Number 2, Year 2024
DOI: https://doi.org/10.62051/ijcsit.v3n2.11
Journal homepage: https://wepub.org/index.php/IJCSIT/index

A Review of Microgrid Power Quality Disturbance Identification Studies

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ABSTRACT

Microgrid is an efficient large-scale distributed generation technology, which is an important component of smart grid gradually replacing the traditional power system. With the wide application of power electronic devices in various fields, the problems of harmonic distortion, voltage sag, and voltage swell of power grid have also arisen, seriously endangering the safety, stability, and normal operation of the power grid. This article provides a comprehensive review of the identification techniques for power quality disturbances in microgrids, covering the methods based on time-frequency domain and image coding with deep learning. The background and current situation of power quality disturbances in microgrids are analyzed in a more comprehensive way, and the advantages and disadvantages of various commonly used analysis methods are compared.

KEYWORDS

Microgrid; Power quality disturbance; Time-frequency analysis; Artificial intelligence; Deep learning

1. INTRODUCTION

A microgrid is a miniature power system consisting of distributed power sources, loads, energy storage devices, control devices and so on. Distributed power sources are grid-connected or unbundled with many advantages; they can utilize energy resources efficiently, are easy to install, and at the same time can flexibly cope with a variety of application scenarios. These advantages make distributed power a highly sought-after method of energy generation and management. Mini-grids also maximize the efficiency of distributed power usage and provide a reliable guarantee for the safe operation of the power system. At the same time, mini-grids usually consist of a single independent node connected to a larger grid, and this particular grid structure has many advantages. One of the most important is that the grid connection of mini-grids can reduce the impact on the large power grid, thus improving the reliability of its power supply and increasing the operational efficiency of the entire power grid system. Therefore, microgrids have an important role in modern power systems. In recent years, microgrids have received widespread attention and have been the subject of a great deal of research in various countries.

Therefore, to fully utilize the advantages of microgrids, the first step is to fundamentally solve the problems in the power system; how to quickly and accurately determine the types of power quality disturbances is one of the important technologies of microgrids at present, and the correct identification of the types of disturbances can lay the foundation for dealing with power quality problems in the future [2].

2. POWER QUALITY DISTURBANCE IDENTIFICATION METHOD BASED ON TIME-FREQUENCY DOMAIN

To realize the comprehensive remediation of microgrid, it is necessary to quickly and accurately judge the disturbance signals in the microgrid network and identify the type of disturbance. At present, many scholars at home and abroad are devoted to accurately recognizing power quality disturbance signals. With the continuous development of power grid construction, various disturbances are more and more used in the power grid. Power quality disturbance identification is an important issue in power grid construction, which includes the extraction of disturbance features and the discrimination of disturbance types, and these two key issues are to use specific analysis methods to obtain feature information that can distinguish various disturbances, and to use classifiers with good performance to make accurate judgments on disturbance signals.

(1) Characterization of power quality disturbances in mini-grids

The feature extraction of power quality disturbance needs to rely on excellent power quality detection algorithms, power quality detection algorithms can decompose the interference signal, so as to obtain more feature information. In recent years, the power quality testing technology in China's power system has been improving day by day, and a variety of excellent power quality testing methods are emerging. At present, there are three main types of power quality disturbance detection methods, which are time-domain based analysis method [5], frequency-domain based analysis method [9] and time-frequency domain based analysis method [12].

The time domain analysis method is the most direct method in the current power system, but the current power quality testing methods have lagged behind the development of the power system, and new technologies and methods need to be introduced to meet the requirements of the power system for quality testing. Compared with the time-domain analysis method, the frequency-domain analysis method is more suitable for the analysis of stable interference signals, and is currently widely used in the fields of harmonic detection, interharmonic detection, and flicker fluctuation detection. However, due to the grid effect, it leads to spectral leakage, which affects the detection accuracy. Since the harmonics of microgrids are random and unstable, it is difficult to obtain satisfactory results with conventional harmonic analysis methods. Therefore, a time-frequency domain analysis method that combines time domain and frequency domain analysis is proposed.

More and more microgrid power quality disturbance detection methods adopt the time-frequency domain based analysis method, which can provide more accurate and comprehensive disturbance characterization, and thus has been widely used in microgrid power quality disturbance detection. Existing representative methods for time-frequency domain analysis include S-transform [6], wavelet transform [11], Hilbert-Huang transform (HHT) [12], and LMD algorithm [13].

Wavelet transform is a signal analysis method inherited and developed from Fourier transform. It adopts multi-scale local analysis, which can efficiently analyze signals in the time-frequency domain, and has the advantage of providing more accurate and comprehensive characterization in both the time and frequency domains. Therefore, wavelet transform has been widely used in the field of signal analysis. Literature [8] analyzed the power quality of microgrids using wavelet analysis techniques, and the results showed that the interference signals in microgrids can be accurately located and identified using wavelet analysis methods. Literature [11] In this paper, a new algorithm for the location and identification of disturbances is investigated using a combination of wavelet techniques and BP neural networks. The method derives the enhancement of Db4 wavelet by Euclidean decomposition, and then separates the interference signal and combines it with the mode maximum to determine the location of the interference spikes; on this basis, the BP neural network is introduced based on the adaptive ability of dynamic variables and the comprehensive evaluation of dynamic feature terms. Literature [15] In this paper, a wavelet transform using a combination of empirical wavelet transform, Hilbert transform and singularity decomposition is introduced to detect the characteristic parameters of the harmonic components; wavelet analysis and support vector machine classifiers are utilized to classify the interference signals. Literature [17] uses wavelet transform and S-transform technique for detection and resolution of interference signals and BP neural network for classification and identification of interference signals.

S-transform is developed from wavelet transform and short-time Fourier transform, which can perform non-destructive time domain transformation of interference signals; S-transform has been widely used in the identification and recognition of power quality interference signals. For example, in literature [18], the S and TT transforms can be used to obtain interference signals from microgrids quickly, so as to accurately identify and recognize the interference in microgrids. However, the S-conversion algorithm generates a large amount of redundancy in the solution. Literature [19] proposes the use of Blackman window S-conversion to obtain the time-frequency pattern of the interference signal. This method utilizes Blackman window S-transformation to process the signal so that it can more accurately characterize the interfering signal in terms of time and frequency. Literature [20] used variational modal decomposition S-transformation and fuzzy C-mean clustering method to detect the types of distributed energy in the distribution network and the various characteristics caused by the operation process, and categorized them so as to achieve power quality monitoring in the distribution network. Literature [21] extracts the feature vectors of the disturbing signals by processing the signals using the bi-resolution S-transform and then utilizes the LVQ neural network to classify and identify these features. This method is able to identify and classify the disturbance signals more accurately, thus improving the efficiency of power quality detection and monitoring.

HHT is a powerful method in power quality disturbance analysis, and the algorithm adopts the combination of empirical modal decomposition and Hilbert transform, which can effectively analyze nonlinear and nonsmooth signals, and can well solve the problems in wavelet transform. Currently, many scholars apply the HHT algorithm and the improved HHT method to power quality disturbances in power systems, e.g., literature [22] proposes an improved HHT algorithm to detect harmonics in power systems and achieves better results. Literature [23] used HHT transform to convert the signal to the time-frequency domain, extracted the features of fault events, and used machine learning techniques to classify these features in order to achieve accurate identification and protection of fault events in microgrids. Literature [24] achieved effective detection of various disturbance signals in microgrids by improved HHT algorithm. In this paper, a combination of wavelet analysis and Hilbert-Yellow transform is used to monitor and identify the transient power quality in microgrids. Literature [26] The method uses wavelet threshold noise reduction technique to identify and detect transient power quality disturbances in microgrids by combining wavelet analysis with Hilbert **-**Yellow Transform and simulates them by computer simulation.

The local mean decomposition (LMD) method produces "endpoint effect" and "modal aliasing" when detecting power quality disturbances, which greatly affects the detection accuracy. The accuracy of detection is greatly affected by the phenomena of "endpoint effect" and "modal aliasing" when detecting power quality disturbance. Literature [27] improves the LMD algorithm and gives a curvature extension method for four-point waveforms, and improves the "endpoint effect" by optimizing the waveforms. The algorithm is accelerated by cubic spline interpolation, which indirectly reduces the influence of "endpoint effect" and "modal aliasing". In addition, an adaptive screening termination criterion based on the judgment termination conditions of the inner and outer loops is given to suppress the "modal aliasing".

(2) Identification of power quality disturbance types in microgrids

In power quality disturbance identification, an important issue is the need to rely on classifiers to accurately identify disturbance types, which classify power quality disturbances according to specific rules. Currently, based on the results of related research at home and abroad, the commonly used classifiers can be summarized as random forest and decision tree classifiers [28-31], neural networks

[32], and support vector machine (SVM) classifiers [34], which can be used in the field of power quality disturbance classification.

Decision tree is a classification model that decomposes an otherwise complex classification problem into a number of simple subproblems through a series of constraints. Random forest, on the other hand, has the advantages of high efficiency, accuracy and interpretability, and has been widely used in the field of data mining and machine learning to effectively deal with large-scale classification problems. Literature [28] combines wavelet analysis and decision tree methods, which can effectively classify multiple individual disturbances. Literature [29] analyzed nine different types of power quality disturbances by performing an improved S-transformation and decision tree. Literature [30] built on this foundation by analyzing five different attribute vectors using dynamic metrics and S-transformation, and simply classified 10 different types of power quality disturbances using decision trees. Literature [31] improved on the problem of decision tree difficult to be constructed in complex power quality disturbances by S-transformation and gave a new decision tree construction algorithm with good experimental results. However, Random Forest has overfitting phenomenon in some noisy cases, and there are unreliable attribute weights in some cases with high attribute levels.

BP neural network is a kind of forward neural network, this neural network structure is simple, easy to implement, and suitable for a variety of different tasks and application scenarios, so it has been widely used in the field of machine learning and data mining. Literature [32] utilizes probabilistic neural networks to classify power quality disturbances. Literature [33] used multilevel perceptron neural network to detect the harmonic components (amplitude and phase) of the distribution network and examined the 3rd, 5th and 7th harmonic components on a simulation platform, and the results showed that the use of neural network algorithms can reduce the detection error while ensuring real-time performance.

The support vector machine not only has better generalization performance and robustness, but also can deal with high-dimensional data, which is suitable for a variety of complex data classification and prediction problems. Literature [34] implements disturbance signal identification for solar power microgrid systems using SVM classifiers. In order to speed up the construction of SVM classifiers, LS-SVM has been widely used in the identification of power system disturbances. For example, literature [36] combines LS-SVM with wavelet packets to recognize power quality disturbances, which effectively improves the recognition of power quality disturbances. Literature [37] used SVM to establish an SVM-based static classification method to classify different types of power quality disturbances and obtained good results. Literature [38] improves SVM, meanwhile, a new disturbance classification algorithm is given in this paper, which also has some application value in the classification of power system disturbance signals. Among them, the literature [39] combined the decision tree and SVM to test 11 kinds of disturbances, and finally the 11 kinds of disturbances were accurately recognized.

3. DEEP LEARNING BASED POWER QUALITY DISTURBANCE IDENTIFICATION METHOD

With the continuous development of smart grid, the power data is also increasing rapidly, and the traditional shallow machine learning is difficult to mine useful information from the massive data. Because the power quality disturbance signal is a one-dimensional time series, and Convolutional Neural Network (CNN) [40] is the fastest developing and relatively most mature deep learning model. Therefore, deep learning based power quality disturbance identification methods have been developed in recent years.

Literature [41] verified that the deep learning-based stacked self-coding algorithm for the identification of power quality disturbances enhances the network's immunity to interference on the basis of improving the classification effect. In the literature [42], a deep convolutional neural network was designed for feature extraction and classification of disturbance signals in power systems, and a neural network for power quality disturbance identification and classification was used. A 1D-MR model based on Inception-ResNet is proposed, which is used to analyze the characteristics of power quality disturbance signals and combined with a neural network to construct a one-dimensional MR deep convolutional neural network for identifying and classifying power quality disturbances. Literature [43] proposed a new algorithm for feature extraction and classification using spectrogram and CNN's, and another one-dimensional CNN for immediate recognition. By comparing with each other, it is verified that the two algorithms' have high accuracy for power quality disturbance identification.

In addition to the above time-frequency analysis method, an image coding method can be used to convert a one-dimensional time series into a two-dimensional image for feature extraction and classification, but this type of method is only used for grid power quality disturbance identification, for example, literature [44] uses the Gram's angle field method to map the disturbance signal into a two-dimensional image and automatically extracts the features with a convolutional neural network, and the accuracy rate can reach 99.91%. Similarly literature [45] used Gram's corner field to transform one-dimensional power quality disturbance signal data into two-dimensional images, and then trained and classified them by an improved migration learning model. Literature [46], on the other hand, uses the same image conversion method, followed by automatic feature extraction and classification by graph convolutional neural network. In contrast, literature [47] uses a two-channel Gram Corner Field to fully preserve the temporal features by improving the Gram Corner Field to convert it into a 2D image, and then uses a deep residual network for feature extraction and classification, and the comprehensive recognition rate for 25 types of perturbations can reach 94.2%. Literature [48], on the other hand, uses recursive graph algorithm to obtain 2D images of power quality disturbances, and then uses long and short-term memory neural networks for feature extraction and classification. The literature combines the time-frequency analysis method with the signal decomposition method, and the feature component color map and the wavelet time-frequency map are derived from the perturbation signal for the combination of feature images respectively, and then the corresponding convolutional neural network design is carried out according to the resulting images, which has a high recognition accuracy. Literature [50] utilizes phase space reconstruction and deep convolutional neural network approach for recognition. Literature [51] performs s-transform on power quality disturbance signals, then feature extraction with CNN, then convolution by graph convolutional neural network, then feature enhancement by AFEN module, and finally classification by convolutional neural network, which can achieve high recognition accuracy.

4. CONCLUSION

Microgrids are small power systems that can be operated in both grid-connected and islanded modes. Power quality perturbations, such as voltage drops and rises, may affect the performance of microgrids. One way to analyze these perturbations is through feature extraction, which consists of identifying relevant features of the perturbations. Manual feature extraction is a traditional approach that relies on human expertise, which is then added to the classification for identification whereas automated feature extraction uses algorithms, such as deep learning, to automatically extract features and then automatically identify them with a classifier. Both methods have their own advantages and disadvantages and the choice of method depends on the specific application and available resources. Overall, automatic feature extraction methods, especially deep learning, have shown more accurate and efficient results in improving the accuracy and efficiency of power quality disturbance analysis in microgrids.

ACKNOWLEDGEMENTS

This work was supported in part by the graduate innovation fund of Sichuan University of Science and Engineering Y2023317.

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